Establishment of standardized site index of needle-leaved forest and its application in evaluation of site quality in Daxing'an Mountains

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Abstract: The site index lists of the artificial *Larix gmelini* and *Pinus sylvestris* var. *mongolica* forests in Daxing'an Mountains region were analyzed by the principle of the two-point method. The standardized growth model of the artificial needle-leaved forest was set up. According to the model, the each growth-index class and theoretical values of each age-class were calculated, and the standardized site index list was constituted. The test of the theoretical values showed that the standardized site index list meet the demand of precision. This study resolved the conversions of site indexes between the same species in different site types and the different species in different site types for needle-leaved forests in Daxing'an Mountains region.
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Introduction

Evaluation of forest site is to evaluate the woodland on which forest depended for existence, and productive capacity of forest growing in different environment (Liang *et al.* 1999). Among the many methods of evaluation of forest site, the site index list, based on age and dominant height, with characteristics of convenience and simplicity, was widely accepted and used throughout the world, due to the age and dominant height are credible and easily inquisitive indices.

The guiding curve method of single specie (Li and Hong 1997) is one of site index list methods, which has been widely adopting in evaluating site quality up till now in our country. Since 1980 the site index lists of *Larix gmelini* and *Pinus sylvestris* var. *mongolica* had been compiled (Hao 1987) for Daxing'an Mountains region, which play roles in instructing the management and production of forest. However there has not been an uniform method for compiling the lists for different regions, so that the error of contrast evaluation always happens between different areas. As the site quality evaluation by single specie cannot meet the need of future forest management, the site indices should be compared and converted among the species under the same site condition, in order to accurately evaluate the productivity of woodland, meet the need of reasonable management and utilization of forest, and afforestation design.

In this paper, we regarded site index list of plantation of *Larix gmelini* and *Pinus sylvestris* var. *mongolica* as basic materials to constitute the standardized growth model for needle-leaved forest of Daxing'an Mountains region by two-point method. According to the model, the theoretical values of growth-index class and age class were calculated and tested, and the standard site index lists were compiled.

Principle and methods

Principle

The basic principle of two-point method is that the ratio of the dominant height of the trees in certain age class to the dominant height of standard ages was used as the relative dominant height to express the productivity of forest stand, which was not limited by species and areas (Zhong 1990.)

In dominant height curve cluster of site index, $H_i=f_i(t)$, (H_i stands for the value of dominant height of No i site index list, $f_i(t)$ stands for functional expression of H_i, t stands for age ,i=1, 2, $\cdots G$, G stands for the totality of collected site index list). Use $H_i(j)$ to express the dominant height of standard age, then the curve cluster of relative dominant height can be expressed by $H_i'=f_i(t)/H_i(j)$, which can standardize all the collected site index lists. New sample i was composed under the circumstances of keeping each curve prototypes. According to the characteristics of new samples the classified age of relative dominant height and the growth-index class are determined to form the relatively dominant height series and prototypes growth curve cluster

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including two ages. The result showed that if different forest stand has the same growth values at any two ages, the growth values of forest stands is also the same at any other ages, at the same time this is also possible to all forest stands, and this principle was named the two-point method.

Method

According to the above principle, all collected site index lists were divided into groups by 5-year age class, the sample unit of standardized site index for artificial needle-leaved forest in Daxing'an Mountains region was established. We calculate and analyze it with the following process.

Relativizing numerical values

In order to easily compare and analyze the degree of dissimilarity in the different regions or different species, we regarded dominant height of standard age for center index class as 100% and calculated relative values of dominant height at different age class by equation (1).

$$Y = H_i / H_i(20)*100\% \quad (1)$$

Where Y is the relative values of dominant height, i is age, H_i is dominant height of i age class, $H_i(20)$ is dominant height of standard age (20 a) .The results of calculation see Table 1.

Table 1. Calculation of relativizing numerical values of tree height

Age (a)	*Pinussylvestris* var. *mongolica* in Wu'erqihan area		*Larix gmelini* in Wu'erqihan area		*Larix gmelini* in Balin area		*Larix gmelini* in Yakeshi area	
	Absolute value (m)	Relative value (%)	Absolute value (m)	Relative value (%)	Absolute value (m)	Relative value (%)	Absolute value (m)	Relative value (%)
5	1.2	13.3					2.8	32.3
10	3.1	34.4	5.1	51.0	4.2	46.7	5.38	44.6
15	6.5	72.2	7.8	78.0	6.7	74.4	9.06	75.1
20	9.0	100.0	10.0	100.0	9.0	100.0	12.06	100.0
25	11.1	123.3	11.8	118.0	11.04	122.7	14.39	119.3
30	12.1	134.4	13.1	131.0	12.81	142.3	16.29	135.1
35					14.32	159.1	17.9	141.7
40					6.5	173.3	19.3	160.0

Age for classifying site index class and class interval

All the data of the tree height were classified into class at age of 25, and the class intervals of relative site index were defined as 2%.

Growth Curve Model and Parameter Calculation

By applying Richard growth curve equation (Lang *et al.* 1999), we simulated site index curve of each class to calculate the parameter *A, B, K.* The equation is as follows:

$$H = A(1-e^{-kt})^B \quad (2)$$

where H is dominant height (site index), t is age; e is the base of natural logarithm, A, B, and K stand for parameters of curve. According to the two-point methods mentioned above, the parameter of guiding curve should be content with t =20 (standard age), H=100%. Substituting above parameters into the equation (2), we can obtain the equation (3)

$$100 = A(1-e^{-20k})^B \quad (3)$$

The equation (3) requires K must be a constant when carrying out iterative computations. According to K=1.974997E-02, we can educe A, B and correlation coefficient (R), standard difference (S) of each area (see Table 2).

Table 2. Parameters of guiding curve of the site index of each area

Index	*A*	*B*	*K*	*R*	*S*
2	257.7423	0.8631	0.0197	0.9977	0.6278
3	284.7229	0.9519	0.0197	0.9984	0.6924
4	315.4992	1.0427	0.0197	0.9987	0.7584
5	353.9544	1.1477	0.0197	0.9996	2.3892
6	370.2195	1.1840	0.0197	0.9992	2.4647
7	387.0381	1.2238	0.0197	0.9977	2.5476
8	415.9238	1.2861	0.0197	0.9963	2.6774
9	465.0827	1.3909	0.0197	0.9970	2.8954

Substituting the parameter A, B, K from the Table 2 into equation (2), we counted out the dominant heights (H_i) of each age class in terms of age class 5, 10, 15, 20···40, then substituted H_i into equation (1) and educed the relatively dominant heights of each age class. The result showed that the relatively dominant heights of each age class presented close linearly dependence with site index class except for the 5-year age class. On the basis of this, the linear regression model (equation 4) was established between relative dominant height and site index class of each age class over 10 years:

$$y_i=a_i+b_iH_i \quad (4)$$

where i is age gradation, y_i is relatively dominant height of the i age-class, a_i, b_i is parameter, and H_i is site index class of the i age-class. According to equation (4), we calculated parameters (a_i, b_i) of regression equation of each age-class and correlation coefficient r_i (see Table 3).

Table 3. Linear regression parameters of each age-class

Age class	a_i	b_i	r
10	62.4238	-2.7202	-0.9999
15	86.5048	-2.1691	-0.9999
20	-	-	-
25	-	-	-
30	119.6241	3.4430	0.9785
35	135.5064	5.8264	0.9897
40	131.6833	6.1417	0.9999

Substituting regression parameters from Table 3 into equation (4), we set up the standardized site index list of artificial needle-leaved forestry in Daxing'an Mountains region (see Table 4).

Table 4. The standardized site index of artificial *Larix gmelini* and *Pinus sylvestris* var. *mongolica* forests in Daxing'an Mountains region (%)

Age class	2	3	4	5	6	7	8	9	10	11	12
5					23.1	22.7	21.6	18.8	16.0	14.0	12.0
10	57.0	54.3	51.3	48.8	46.1	43.4	40.7	37.9	35.2	32.5	29.8
15	82.1	80.0	77.9	75.7	73.5	71.3	69.2	67.0	64.8	62.7	60.5
20	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
25	114.0	116.0	118.0	120.0	122.0	124.0	126.0	128.0	130.0	132.0	134.0
30	126.5	129.9	133.4	136.8	140.3	143.7	147.2	150.6	153.1	157.5	160.9
35	133.5	140.0	145.0	150.0	155.0	160.0	165.4	170.6	175.9	181.0	186.0
40	144.0	150.1	156.2	162.4	168.5	174.7	180.8	187.0	193.1	199.2	205.4

Test of standardized site index list

The relatively dominant height (y) was defined by $y=H_{(25)}/H_{(20)}$.

Using linear interpolation method to define site index value(I')

$$I'=I+j \quad (5)$$

where I stands for site index class, and

$$j=[H_{c(t)}-H_{B(t)}]\ /\ [H_{A(t)}-H_{B(t)}] \quad (6)$$

where $H_{A(t)}$ and $H_{B(t)}$ are adjacent site index classes in standardized site index list, $H_{c(t)}$ stands for undecided parameter-- relative dominant height (y).

The absolute values of dominant height in each age class (H_{top}) were calculated by the following equation

$$H_{top}=[H_{A(t)}-(H_{A(t)}-H_{B(t)}\ {}^*j)^*H_{oi}] \quad (7)$$

where H_{oi} is the absolute value of dominant height at the standard age.

Now we take an example to illustrate the test method. The 20-year and 25-year dominant heights from original Table was 10 m and 12.39 m in Balin site index list of Daxing'an Mountains region, respectively, and the relatively dominant height $y = H_{(25)}/H_{(20)}= 12.39 /10 * 100 \% =123.9$. From Table 4, we knew that the relatively dominant height (y) at 25 age-class lay between the site index class 6 and 7, and by equation (5) we educed the value of standardized site index of the relative dominant height (6.95), then calculated the dominant heights of each age-class by equation (7) (see Table 5).

Table 5. The comparison between original list's values of artificial *Larix gmelini* forest in in Balin area and the computing values of standard site index in Daxing'an Mountains region

Age /a	Relative values of dominant height /%	Dominant height /m		
		Original list	Computation	Difference
10	43.2	4.32	4.34	–0.02
15	72.6	7.26	7.13	0.13
20	100.0	10.0	10.0	0
25	123.9	12.39	12.39	0
30	144.1	14.41	14.40	0.01
35	160.7	16.07	16.00	0.07
40	174.2	17.42	17.47	-0.05

Each index class of all site index lists in Daxing'an Mountains region was tested by this method. The result is credible, and the errors for most values were 0-5 cm, except that few values were 10-20 cm, which coincided with original data.

Table 6. Test of standardized site index of artificial *Larix gmelini* and *Pinus sylvestris* var. *mongolica* forests in Daxing'an Mountains region.

Age (a)	Wu'erqihan area																				
	Pinus sylvestris var. *mongolica*									*Larix gmelini*											
	8.55*			7.50			6.65			4.09			4.00			3.33			2.00		
	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH
10	2.5	2.7	-0.2	3.1	3.4	-0.3	3.7	4.0	-0.3	5.7	5.7	0	5.1	5.2	-0.1	6.5	6.4	0.1	4.4	5.1	-0.7
15	4.8	4.8	0	5.6	5.6	0	6.5	6.5	0	8.6	8.6	0	7.8	7.8	0	9.5	9.5	0	7.0	7.4	-0.4
20	7.0	7.0	0	8.0	8.0	0	9.0	9.0	0	11.0	11.0	0	10.0	10.0	0	12.0	12.0	0	9.0	9.0	0
25	8.9	8.9	0	10.0	10.0	0	11.1	11.1	0	13.0	13.0	0	11.8	11.8	0	14.0	14.0	0	10.3	10.3	0
30	10.5	10.4	0.1	11.5	11.6	-0.1	12.7	12.8	-0.1	14.6	14.7	-0.1	13.1	13.3	-0.2	15.7	15.8	-0.1	11.2	11.4	-0.2

Age (a)	Balin area																	
	Larix gmelini																	
	8.13			7.86			7.00			6.11			5.91			5.00		
	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH
10	3.1	3.2	-0.1	2.9	2.9	0	4.3	4.3	0	4.2	4.1	0.1	5.1	5.1	0	6.0	5.9	0.1
15	5.6	5.5	0.1	4.9	4.9	0	7.3	7.1	0.2	6.7	6.6	0.1	8.2	8.1	0.1	9.0	9.1	-0.1
20	8.0	8.0	0	7.0	7.0	0	10.0	10.0	0	9.0	9.0	0	11.0	11.0	0	12.0	12.0	0
25	10.1	10.1	0	8.8	8.8	0	12.4	12.4	0	11.0	11.0	0	13.4	13.4	0	14.4	14.4	0
30	11.7	11.8	-0.1	10.3	10.3	0	14.4	14.4	0	12.8	12.7	0.1	15.3	15.4	-0.1	16.4	16.4	0
35	13.1	13.3	-0.2	11.6	11.5	0.1	16.1	16.0	0.1	14.3	14.0	0.3	16.9	17.0	-0.1	18.0	18.0	0

Age (a)	Yakeshi area																				
	Larix gmelini																				
	9.17			8.82			8.77			7.79			6.34			5.65			4.50		
	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH	H	H_0	ΔH
5	1.0	1.1	-0.1	1.6	1.5	0.1	1.3	1.3	0	1.9	1.7	0.2	2.2	2.2	0	2.5	2.5	0	2.8	2.8	0
10	1.9	2.3	-0.4	3.1	2.9	0.2	2.5	2.7	-0.2	3.6	3.6	0	4.2	4.4	-0.2	4.8	5.1	-0.3	5.4	6.1	-0.7
15	4.0	4.0	0	4.7	5.1	-0.4	4.0	4.7	-0.7	5.6	6.0	-0.4	6.5	7.1	-0.6	7.8	8.0	-0.2	9.1	9.3	-0.2
20	6.0	6.0	0	7.6	7.6	0	6.9	6.9	0	8.6	8.6	0	9.7	9.7	0	10.8	10.8	0	12.1	12.1	0
25	7.7	7.7	0	9.7	9.7	0	8.8	8.8	0	10.8	10.8	0	11.9	11.9	0	13.1	13.1	0	14.4	14.4	0
30	9.1	9.1	0	11.4	11.4	0	10.4	10.3	0.1	12.6	12.6	0	13.8	13.7	0.1	14.9	15.0	-0.1	16.3	16.4	-0.1
35	10.3	10.3	0	12.8	12.9	-0.1	11.6	11.7	-0.1	14.2	14.1	0.1	15.3	15.2	0.1	16.5	16.6	-0.1	17.9	17.9	0

Note: "*" is relative site index; H, H_0, and ΔH were dominant height of different tree, standardized site index dominant height (theoretical), difference respectively (m).

Application

The standardized site index can extend the application of site index. It is not only suitable for evaluating site quality, but also can provide background materials for the comparison of adaptabilities and increment between different tree species, aimed at forestry production division and matching the species with the site.

Predicting growth process of dominant height

The dominant heights measured were 9 m and 4.54 m respectively at ages of 20 and 10, and the relative dominant height is y=4.54/9×100%=50.4. From Table 4, we know that the relatively dominant height (y) at 10-age-class lay between the site index class 4 and 5, and by equation (5) we educed the value of site index (4.36 m), then, calculated the dominant heights of each age-class from 10-year to 40-year by equation (7).

Compiling curve group of site index

After inquired the values of two dominant heights each age-class, we can determine its site index class and compile the curve group of site index.

Conversion of the site index between tree species (Luo 1989)

According to the corresponding value of the dominant height and age for each tree species, the matching equation was set up with any site index as independent variable

SISP=[PLSI(SP)/PLSI(dominant)]*SITE

where SISP stands for the site index of calculating species, PLSI(SP) stands for relative site index of calculating species, PLSI (dominant) stands for the relative site index of some given species, and SITE stands for the standardized site index of some given species.

Now we take the evaluation of conversion of the site index between species as example to illustrate the practical application values of the standard site index. The site indexes can be converted and evaluated between the same species in different site types and between the different species in different site types. The 20-year dominant heights of artificial *Larix gmelini* forest was 10 m in Balin area of Daxing'an Mountains region, let its dominant height (site index) is 100%, and then the dominant heights of *Pinus sylvestris* var. *mongolica* and *Larix gmelini* in Wuerqihan area and *Larix gmelini* in Yakeshi area at the age of 20 were 80%, 90% and 86%, respectively. On the basis of this, the conversion lists of site index for each species between different areas could be educed (Table 7).

Table 7. Site index conversion of different species in different areas

Age (a)	Standardized site index (dominant height, m)	Converted site index (dominant height, m)		
	BaLin area	Wu'erqihan area		Yakeshi area
	Larix gmelini	*Pinus sylvestris* var. *mongolica*	*Larix gmelini*	*Larix gmelini*
	100*	80	90	86
10	4.3	3.4	3.9	3.7
15	7.1	5.7	6.4	6.1
20	10.0	8.0	9.0	8.6
25	12.5	9.9	11.2	10.8
30	14.4	11.5	12.7	12.4

Note: "*" stands for relative site index.

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